STUDY CONCERNING THE EFFECTS OF PLASMA NITRIDING ON THE CHARACTERISTICS OF STRUCTURAL ALLOY STEELS

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ABSTRACT: Due to the many technical-economical advantages it offers in comparison to the classical heat treatment processes, plasma nitriding has in recent years considerably enlarged its range of industrial applications. The main purpose of plasma nitriding is to provide advantageous conditions of the parts' machinability and reliability, by modifying their chemical composition, the structure and reducing any internal stresses. Nitrogen diffusion in the base material's crystal lattice creates in the parts' superficial layer compounds that determine an increase in wear and corrosion strength and an improvement of the general tribological properties. In the current paper, the authors focus on the kinetics of forming and on the hardness of layers obtained after plasma nitriding in structural steels such as 39CrAlMo6-9-2, 42CrMo4, 18CrMn4-4 and 40Cr4.

KEY WORDS: plasma nitriding, structural alloy steel, hardness, microstructure

1. INTRODUCTION

Plasma nitriding is a relatively new thermochemical treatment, used for achieving in metallic parts a specified structural state, a specified chemical composition and not least improved mechanical properties, especially with regard to the superficial hardness, so that the part can work in the intended functioning conditions for as long as possible, without any significant damage or failure occurring to it.

One of the most important current issues in the experimental research efforts related to the plasma nitriding process in many countries is the adequate employment of metallic materials in products (parts, tools, blanks) in order to maximize the effect of the applied thermochemical treatment in terms of improved properties. The efficient use of metals and their alloys represents a major objective for the production area as well as for the customers, which implies taking advantage of all technological characteristics of the materials in question.

In the last years, the thermochemical treatment of plasma nitriding has expanded considerably its range of industrial applications with respect to the metallic materials employed, but also with respect to the type, shape and destination of parts, especially because it offers numerous technical-economical advantages over the classical heat treatment processes [1], [2], Plasma nitriding is used especially for complex parts that are subjected to intense wear and fatigue stresses, to contact pressure, shocks, and corrosion in wet environments [4], [5]. This allows the treatment of parts with light or average gauge with simple or complex geometry as well as heavy parts (shafts, paddles, gear wheels), with dimensions that can reach 11 meters in length and 3 – 3.5 meters in diameter [4], [5]. The use and spreading of plasma nitriding technology requires knowledge of possible results (structure, hardness, layer width etc) regarding the steels conduct after applying this surface thermo-chemical treatment, [6], [7], [8].

In this context, the authors of the current paper considered useful to present some of the studies and experimental researches carried out by them with regard to the kinetics of forming and the hardness of layers obtained after a plasma nitriding thermo-chemical treatment on some structural steel types used in mechanical engineering - 39CrAlMo6-9-2, 42CrMo4, 18CrMn4-4 and 40Cr4.

2. EXPERIMENTAL RESULTS

The researches were carried out using a plasma nitriding plant INI – 30, within which the samples were suspended with a device that allows a symmetrical positioning of the test samples and of the reference samples, so as to allow also carrying out temperature measurement. The gas used was pure ammonia.

The samples were made cut in the shape of disks of various dimensions according to the material type, cut from bar-shaped blanks.

After the preliminary heat treatments in all the cases the parts have been grinded plan-parallel (Ra = 0,025 mm), and then degreased with westrosol. Also, they have been cleaned by means of cathode spraying (at the beginning of each process corresponding to the tested materials) at a voltage of 100 V and a pressure of 40 Pa for approximately 15 minutes.

After the nitriding, metallographic samples have been extracted for macroscopic investigations, microscopic analyses and microhardness testing that allowed to determine the depth of the nitrided layer. Before the metallographic etching, the samples have been grinded on the plane surfaces to a depth of 0.5 mm in order to remove the nitrided layer. In this state, a hardness tester was used with a load of 2 N for determining the HV macrohardness.

A. In the first experiment the material used for the test samples was a 39CrAlMo6-9-2 steel bar (Ø 60 x 200mm) having the chemical composition: 0.42 %C; 0.51 % Mn; 0.28 %Si; 1.69 %Cr; 0.28 %Mo; over 0.5 %Al. The samples had the shape of disks of Ø 60 x 20 mm dimension that was afterwards heat treated (quenching followed by high tempering at 550°C). The tests were carried out with 5 samples each heated at the temperatures of 480°C, 510°C, 540°C, with process times of 1, 2, 4, 6, 8 and 16 hours. The working voltage was of 700 V, the working pressure 240 – 320 Pa. The mentioned parameters were continually monitored and registered on the plant's control panel.

Figures 1 and 2 present the microstructures (x 400) in test samples made of 39CrAlMo6-9-2 steel subjected to plasma nitriding (8h / 480°C and 16h / 540°C, respectively).

B. The next experiment carried out by the authors used samples made of 18CrMn4-4 steel (0.21 %C; 0.44 %Mn; 1.04 %Cr and 0.32 %Si). The test samples have been made out of a bar (Ø 70 x 250 mm) also having the shape of disks with dimensions of Ø 70 x 25 mm.

After cutting, the material has been heat treated (quenching followed by high tempering at 550°C). After this treatment the microstructure presented partially spheroidized carbides and a certain amount of free ferrite.

Figure 1. Microstructure (x 400) in the cross-section of a plasma nitrided test sample made of 39CrAlMo6-9-2 steel (8h / 480 °C)

Figure 2. Microstructure (x 400) in the cross-section of a plasma nitrided test sample made of 39CrAlMo6-9-2 steel (16h / 540 °C)

The tests have been made at temperatures of 500 °C and 550°C and at pressures correlated accordingly with these temperatures (values between 125 – 750 Pa). Each pair of values temperature-pressure have been processed for: 1; 2; 3; 4; 6 and 8 hours, in each case being treated 5 samples.

Figures 3 and 4 present the microstructures (x 400) in the cross-section of plasma nitrided test samples made of 18CrMn4-4 steel (8h / 500°C and 8h / 550°C, respectively).

C. For the third experiment the test sample material was a bar with dimensions of Ø 65 x 150 mm made of 42CrMo4 steel (0.39 %C, 0.59 %Mn, 0.28 %Si, 1.04 %Cr and 0.15 %Mo). The disk-shaped test samples (Ø 65 x 15 mm) have again been subjected to a hardening treatment (quenching followed by high tempering at 550 °C).

The tests corresponding to this phase have been carried out at three different temperatures: 450°C, 500°C and 550°C. At each temperature the samples were treated for periods of time of: 1, 2, 4, 8 and 16 hours, respectively, for each pair temperature-time being used 5 test samples. The working voltage was of 700 V and the pressure inside oscillated between 215–380 Pa function of the working temperature.

Figures 5 and 6 present the microstructures (x 400) in the cross-section of plasma nitrided test samples made of 42CrMo4 steel (8h / 480°C and 16h / 540°C, respectively).

D. The metallic samples subjected to the last experiment have been made of a 40Cr4 steel having the following chemical composition: 0.41 %C; 0.64 %Mn; 1.05 %Cr; 0.28 %Si.

The test samples, disks with dimensions of Ø 60 x 10 mm have been divided into two different lots. The test samples in the first lot were subjected to an annealing heat treatment. The test samples in the second lot were subjected to hardening treatment (quenching followed by high tempering at 550 °C).

In the annealed state, the structure consisted of polyhedral ferrite and pearlite grains in approximately equal quantities, while in the case of the hardened state the structure consisted of tempering sorbite (fig. 7).

The test have been carried out at temperatures of 480°C and 520°C and at pressures correlated with these temperatures (values between 0.8 – 1.2 torr). For each pair of temperature-pressure values, there were used 5 test samples.

Figure 3. Microstructure (x400) in the cross-section of a plasma nitrided test sample made of 18MnAlCr11 steel (8h / 500°C)

Figure 4. Microstructure (x 400) in the cross-section of a plasma nitrided test sample made of 18CrMn4-4 steel (8h / 550°C)

3. CONCLUSIONS

■ From the analysis of the microstructure of the combination layer resulted after plasma nitriding the 39CrAlMo6-9-2 steel, the authors could determine that none of the treatment cycles applied shows a continuous combination area with a separation limit from the base material. Nonetheless, there could be noticed a presence of acicular nitrides and an accentuation of the grain limits. The amount of globular carbides decreased in the vicinity of the surface (figures 1 and 2).

Figure 5. Microstructure (x 400) in the cross-section of a plasma nitrided test sample made of 42CrMo4 steel (8h / 500°C)

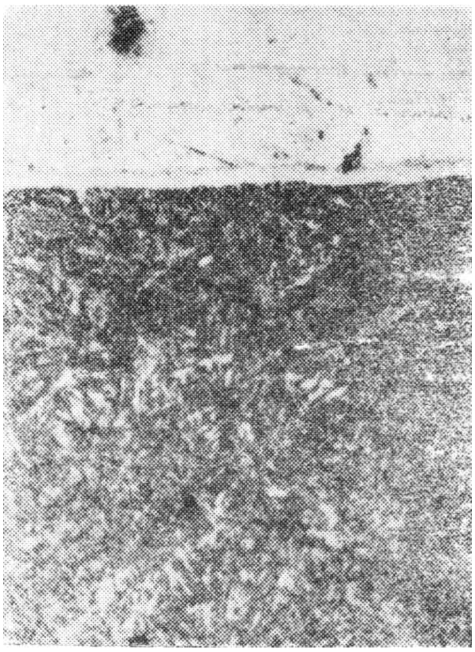

Figure 6. Microstructure (x400) in the cross-section of a plasma nitrided test sample made of 42CrMo4 steel (8h / 550°C)

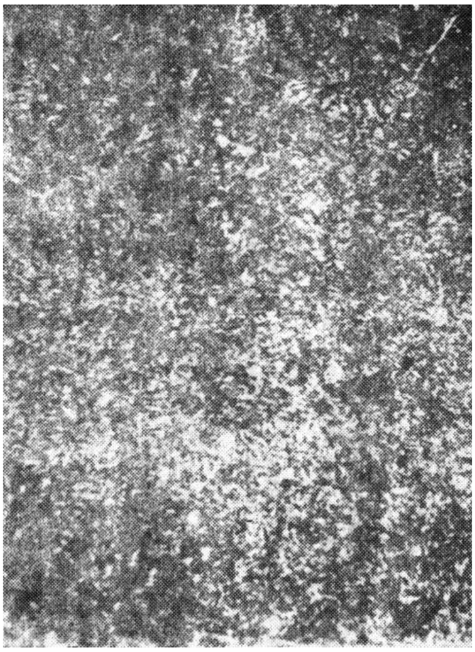

Figure 7. Microstructure (x 500) in the cross-section of a plasma nitrided test sample made of 40Cr4 steel (hardened initial state)

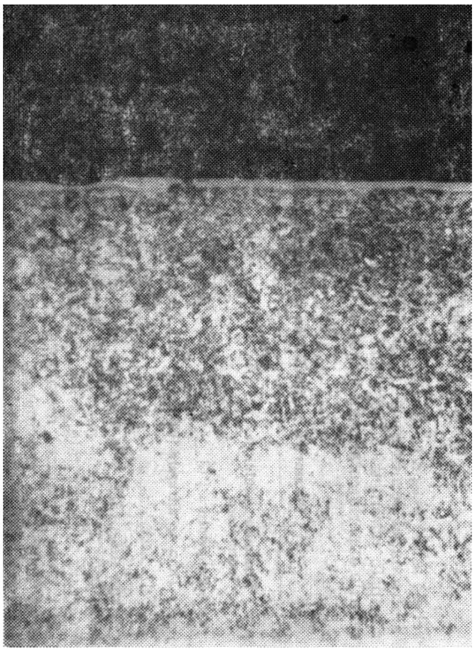

Figure 8. Microstructure (x 500) in the cross-section of a plasma nitrided test sample made of 40Cr4 (hardened initial state) 12h / 550°C

■ An analysis of the microstructure of the plasma nitrided layer of the 18CrMn4-4 steel revealed the existence of a combination layer delimited from the diffusion layer (figures 3 and 4). The depth of this layer varied between 2 μm (for the process parameters 1h / 500 °C) and 9 μm (for 8h / 550 °C). Under the formed combination layer, there is a diffusion layer, its depth being determined by tracing the microhardness profile.

■ For the steel 42CrMo4, the analysis of the combination layer's microstructure showed the presence of a continuous combination layer separated from the base metal (figures 5 and 6). The depth of this layer varied between 1 μm (for the process parameters 1h / 450 °C) and 12 μm (for 16h / 550 °C). The structure of the base metal remained unchanged, i.e. a structure hardened through the presence of globular carbides.

■ With regard to the steel type 40Cr4, the metalographic investigations (fig. 8) revealed the existence of two different layers:

- a white layer with a depth in the order of microns and consisting of γ mono-phase nitrides of type Fe_4N (that has very good wear and viscosity properties).
- the diffusion layer, right after the white layer, with thicknesses between 0,1 – 0,4 mm.

Unlike the mono-phase nitride ε ($Fe_{2\text{-}3}N$ or $Fe_{2\text{-}3}C_xN_y$) obtained through the applying of bath nitriding or carbonitriding and which is glance pitched and porous, the γ phase offers very good wear and viscosity properties. In certain situations of complex stress, when the presence of white layer is not wanted, this one can be totally suppressed, by acting on the nitrogen content that diffuses on the surface of the part.

In all studied cases of test samples made of various steel types, plasma nitriding offers a higher superficial hardness compared to that resulted after simple quenching.

■ For all plasma nitriding regimes and for all types of materials used, the macroscopic and microscopic analyses indicated an absence of superficial faults such as scratches or uneven surfaces.

The hardness of the diffusion layer depends a lot on the nature and concentration in alloying constituents, as well as on the nature and quantity of nitrides precipitated on the grains. A powerful precipitation of nitrides leads to a more fragile diffusion layer, a weaker viscosity and implicitly to a lower resistance at fatigue.

The fragility can be eliminated in the case of plasma nitriding by using a free carbon work environment, carbon being the main element in the precipitating of nitrides or carbonitrides on the grains.

4. REFERENCES

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